Optional ERIC Coversheet — Only for Use with U.S. Department of Education Grantee Submissions

This coversheet should be completed by grantees and added to the PDF of your submission if the information required in this form **is not included on the PDF to be submitted**.

GRANTEE SUBMISSION REQUIRED FIELDS

Title of article, paper, or other content

Moderating effects of executive functions and the teacher–child relationship on the development of mathematics ability in kindergarten

All author name(s) and affiliations on PDF. If more than 6 names, ERIC will complete the list from the submitted PDF.

Last Name, First Name	Academic/Organizational Affiliation	ORCID ID
Blair, Clancy	New York University	
McKinnon, Rachel	New York University	
The Family Life Project Investigators	PSU, Frank Porter Graham Child Center Development Center, UNC Chapel Hill	

Publication/Completion Date—(if *In Press,* enter year accepted or completed) Feb 2016

Check type of content being submitted and complete one of the following in the box below:

- ☑ If article: Name of journal, volume, and issue number if available
- ☐ If paper: Name of conference, date of conference, and place of conference
- ☐ If book chapter: Title of book, page range, publisher name and location
- ☐ If book: Publisher name and location
- ☐ If dissertation: Name of institution, type of degree, and department granting degree

Learning & Instruction, Volume 24

DOI or URL to published work (if available) https://doi.org/10.1111/cdev.13065

Acknowledgement of Funding— Grantees should check with their grant officer for the preferred wording to acknowledge funding. If the grant officer does not have a preference, grantees can use this suggested wording (adjust wording if multiple grants are to be acknowledged). Fill in Department of Education funding office, grant number, and name of grant recipient institution or organization.

"This work was supported by U.S. Department of Education **[Office name]** Institute of Education Sciences through **[Grant number]** R305B140037 to **Institution]** New York University .The opinions expressed are those of the authors and do not represent views of the **[Office name]** Institute of Education Sciences or the U.S. Department of Education.

Published in final edited form as:
Learn Instr. 2016 February ; 41: 85–93. doi:10.1016/j.learninstruc.2015.10.001.

Moderating effects of executive functions and the teacher–child relationship on the development of mathematics ability in kindergarten

Clancy Blair[a,*], **Rachel D. McKinnon**[a], and **the Family Life Project Investigators**[b,c,d]

[a] Department of Applied Psychology, 246 Greene St, Kimball Hall, 8th Floor, NYU, New York, NY 10003, USA

[b] Department of HDFS, 110 Henderson South, Pennsylvania State University, University Park, PA 16802, USA

[c] Frank Porter Graham Child Development Center, 521 S. Greensboro Street, CB 8185, NC 27599, USA

[d] Center for Developmental Science, 100 E. Franklin St., CB8115, UNC Chapel Hill, Chapel Hill, NC 27599, USA

Abstract

Academic preparedness, executive function abilities, and positive relationships with teachers have each been shown to be uniquely important for school readiness and success in the early elementary grades. Few studies, however, have examined the joint influence of these readiness variables on early school outcomes. Using data from a prospective longitudinal sample of 1292 children and families in predominantly low-income and rural communities, we found that executive function at child age 48 months and a higher quality relationship with the kindergarten teacher each uniquely moderated the effect of math ability in preschool on math ability at the end of kindergarten. This effect was seen for math ability as measured by the Early Childhood Longitudinal Study-Kindergarten (ECLS-K) mathematics assessment battery but not the Woodcock-Johnson III Tests of Achievement Applied Problems subtest. For children with lower math ability in preschool as assessed by the ECLS-K Math battery, higher executive function abilities and a more positive relationship with the kindergarten teacher were each associated with a higher than expected level of math ability in kindergarten. Conversely, lowest levels of math ability in kindergarten were observed among children with low math ability in preschool and poor executive function or a less positive relationship with the kindergarten teacher.

Keywords

Mathematics; Early childhood; Executive functions; Self-regulation; Teacher–child relationship; Kindergarten

[*] Corresponding author. clancy.blair@nyu.edu (C. Blair).

Early academic ability is a strong predictor of later academic ability. Children with greater knowledge and understanding of letters and number concepts at school entry achieve at higher levels academically in later grades than their less well prepared peers (Duncan et al., 2007). Although academic preparedness plays a prominent role in school readiness (Duncan et al., 2007; Pianta, La Paro, Payne, Cox, & Bradley, 2002), self-regulation abilities, including executive functions as well as social and emotional aspects of self-regulation are also important (Blair & Raver, 2015). For example, children who can effectively hold information in mind in working memory, selectively attend to stimuli, and inhibit irrelevant and distracting information – executive function abilities that in part undergird self-regulated learning and metacognitive skills (Zimmerman, 2008) – achieve at higher levels academically than children who are less adept at these abilities (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; McClelland et al., 2007; Raver et al., 2011). Similarly, children with positive relations and low levels of conflict with teachers, indicative of social-emotional competence, are more likely to demonstrate higher academic performance (Burchinal et al., 2008; Hamre & Pianta, 2001; Liew, Chen, & Hughes, 2010; Schmitt, Pentimonti, & Justice, 2012), particularly when receiving higher quality instruction (Crosnoe et al., 2010).

Predictors of school readiness and early academic progress are well established. Less is known, however, about relations among these predictors. No studies of which we are aware have examined the possibility that effects of aspects of self-regulation such as executive function abilities and the child's relationship with the teacher are most pronounced for children with initially low levels of academic preparedness for kindergarten. Whereas children entering school with well-developed academic skills will likely meet classroom learning goals, higher levels of executive function abilities and more positive relationships with teachers should in theory help children with limited academic preparedness as assessed by standardized measures to capitalize on learning opportunities and to make larger gains than would be expected from preschool level of ability on its own. Executive function abilities would assist children in maximizing engagement in learning activities while close supportive relationships with teachers would provide an increased level of attention and support in learning activities. Teachers provide more explanation and scaffolding for children with whom they report being close (Allington, 1984; Nomi, 2009) and this increased instruction has been shown to be important for academic achievement (Hamre, Hatfield, Pianta, & Jamil, 2014; Hamre & Pianta, 2001). Thus, executive function abilities and positive relationships with teachers may help close an early achievement gap for children with initially low levels of measured academic ability at school entry.

The purpose of our study was to test the hypothesis that executive function abilities and the quality of the relationship with the kindergarten teacher will each individually interact with mathematics ability measured in preschool to predict mathematics ability measured at the end of kindergarten. We focus on early mathematics learning given the generally high metacognitive demand of early math learning and for reasons related to the measurement of early ability in math. Mathematics, even for very young children includes activities focusing on pattern completion and the identification of conceptual relations among problem elements that make substantial demands on reasoning and abstraction (Baker et al., 2010; Blair, Knipe, & Gamson, 2008). Early reading also makes demands on reasoning, for example holding in mind rules for spelling and syntax that are unique to specific letter or

word combinations. Measures of early reading, however, tend to focus on knowledge of letters and words more so than on reasoning. In contrast, measures of early math ability generally include items assessing reasoning and conceptual skills as well as knowledge-based aspects of mathematics. Thus, for conceptual and methodological reasons, we focus our analysis on early mathematics learning but suggest that our approach is also relevant to early reading and to academic achievement more generally.

Methodologically, we focus on a sample at risk for early difficulty in school due to poverty. Children from low-income homes tend to enter kindergarten with less well developed academic abilities than their higher income counterparts (Brooks-Gunn & Duncan, 1997; Duncan & Brooks-Gunn, 1997). It is also well established, however, that children from poverty backgrounds are more likely to enter school not only less prepared academically but also with less developed self-regulation skills (Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Noble, McCandliss, & Farah, 2007). It may be that the combination of poor academic preparedness with poor EF or with a less positive relationship with the teacher is associated with the least positive learning trajectory into kindergarten. If so, this would indicate a group of children who are at high risk for early school difficulty.

1. Aims and hypotheses

The foregoing underscores the importance of understanding how initial math preparedness, executive functioning, and the quality of teacher–child relationships may uniquely and interactively predict academic outcomes in kindergarten. Although prior research has shown the importance of each domain independently, far less is known about relations among these aspects of children's early schooling. This study builds on prior research on school readiness by examining these relations in a large prospective, longitudinal sample in two regions of high poverty in the United States. In light of persistent and increasing gaps in academic achievement associated with poverty (Reardon, 2011), potential moderating effects of executive functions and positive relationships with teachers on the development of mathematics ability between preschool and kindergarten may provide some insight into ways in which to narrow the achievement gap and inform efforts to identify children at highest risk for early school difficulty.

Importantly, to address the foregoing points, we simultaneously examine two highly reliable and widely validated measures of early math ability, namely, the ECLS-K Math assessment from the Early Childhood Longitudinal Study – Kindergarten cohort study and the Applied Problems subtest of the Woodcock-Johnson III Tests of Achievement. The ECLS-K Math battery was developed in response to the need for a sensitive measure of the development of math skills in early childhood whereas the Applied Problems subtest was developed to assess mathematics ability across the lifespan from ages 2–90 years. As such, examination of the two measures provides a more complete understanding of the development of early math abilities with implications for mathematics assessment in early childhood.

2. Method

2.1. Participants

The Family Life Project (FLP) was designed to study young children and their families who live in two (Eastern North Carolina, Central Pennsylvania) of the four major geographical areas of the United States with high poverty rates (Dill, 2001). The FLP adopted a developmental epidemiological design in which sampling procedures were employed to recruit a representative sample of 1292 children whose families resided in one of the six counties at the time of the child's birth. Low-income families in both states and African American families in NC were over-sampled (African American families were not over-sampled in PA because the target communities were at least 95% non-African American). Full details of the sampling procedure appear elsewhere (Vernon-Feagans, Cox & the FLP Investigators, 2013).

Data in the current analysis (N = 1005) were collected during visits when the target child was 48 months old (n = 920; SD = 2 months), of preschool age (n = 907; age M = 60 months, SD = 3 months), and in kindergarten (n = 1005; age M = 71 months, SD = 3 months). Primary caregivers reported children as 54% Caucasian, 46% African American, less than 1% other ethnicities, and half of children were male (49%). Almost three-quarters of the families were low-income (72%). Half of the mothers were not married (52%), almost half of the mothers had a high school education or less (40%), and only 16% had at least 4 years of postsecondary education. At the preschool age data collection, 76% of the children were in child care or preschool classrooms with an average of 1.8 target children per classroom, and the remaining 24% were in home care. At the time of the kindergarten visit, children were nested in 487 classrooms, most of which had 1 target child (52%, range 1–10).

2.2. Procedures

At the 48-month home visit, two researchers visited the family's home and administered an executive function battery as part of a longer battery of tasks with parents and children. At the preschool and kindergarten visits, researchers visited children at school, or at home when in home care, and administered the ECLS-K Math battery, Applied Problems subtest, and the Peabody Picture Vocabulary Test (PPVT) as part of a larger battery of early academic achievement measures. Kindergarten teachers were given a packet of questionnaires to complete that included ratings of the quality of the teacher's relationship with the target child. Teacher questionnaires were distributed in the spring, providing ample time for teachers to assess their relationships with children.

2.3. Measures

2.3.1. Executive function—At the 48-month home visit, children were administered a battery of six executive function tasks assessing working memory, inhibitory control, and attention shifting, and validated for use with 3- to 5-year-olds (Willoughby, Wirth, & Blair, 2011; Willoughby, Wirth, Blair, & the FLP Investigators, 2012). A full description of each task as well as psychometric information can be found in a number of publications (Willoughby & Blair, 2011; Willoughby et al., 2011). The executive function battery included two working memory tasks, three inhibitory control tasks, and one attention

shifting task. The working memory tasks included a span task and a self-ordered pointing task. The inhibitory control tasks included a Stroop-like sound task, a farm animal go/no go task, and a spatial conflict task. The attention shifting task was a flexible item selection task (Jacques & Zelazo, 2001). Each executive function task was presented in an open flipbook format that presented the stimuli on one page and scripted instructions for administration on the other. Children were required to demonstrate an understanding of the rules by completing training trials and up to three practice trials for each task. Tasks were scored during data processing and children were required to complete at least 75% of the trials to receive a score.

Previous analyses with these data, described in Willoughby et al. (2011), used Item Response Theory (IRT) to estimate a child's latent ability on the task. As an alternative to Classical Test Theory (CTT), which weights each item within a measure equally, IRT estimates underlying true score ability by weighting each item according to its difficulty (Willoughby et al., 2011). IRT analyses generate an expected a posteriori (EAP) score—an estimate of the mean of the distributions of true ability for each item of a task representative of the child's true ability—for each child on each task. EAP scores are created on a Z-scale ($M = 0$, $SD = 1$). In the current study, EAP scores across each of the six tasks were averaged for a single score of each child's level of EF at 48 months. As is typical with measures of executive function tasks, the reliability of the EAP composite score was low, $\alpha = .55$.

2.3.2. Teacher–Child relationships—Each child's kindergarten teacher completed the Student–Teacher Relationship Scale (STRS; Pianta, Steinberg, & Rollins, 1995), an instrument designed to assess teachers' perceptions of their relationships with individual children. The 15-item short-form used a Likert-type format and was designed to provide a measure of closeness (e.g., “I share an affectionate, warm relationship with this child”) and conflict (e.g., “This child and I always seem to be struggling with each other”) with a particular child. A composite score was created by averaging the closeness and reverse-scored conflict items. The Cronbach's alpha for the composite score was 0.86, 95% CI [0.85, 0.88].

2.3.3. Mathematics—Two measures were used to assess children's mathematics competency at the preschool and the kindergarten assessments, the ECLS-K Math battery (Rock & Pollack, 2002) and the Applied Problems subtest of the Woodcock-Johnson III Tests of Achievement (Woodcock, McGrew, & Mather, 2001). Both measures have been validated for use with preschool and kindergarten samples, but differ in certain respects. The ECLS-K Math battery was specifically developed for use in the Early Childhood Longitudinal Study-Kindergarten and measures young children's ability in several domains of math problem solving including number and shape (“Tell me what number this is”), relative size (“Point to the stick that is shorter than the bat”), ordinality and sequencing (“Point to the person who is third in line from the drinking fountain”), and addition and subtraction (“If you had three cars and someone gave you two more cars, how many cars would you have altogether?”). In total, there are 66 items on the measure specifically designed for kindergarteners and first graders to be able to answer. Preliminary items are used to route children to questions at three different difficulty levels. In the current sample,

children answered on average 33 items at the preschool assessment and 38 at the kindergarten assessment. Scoring procedures for ECLS-K Math were used to derive standardized T-scores (*M* = 50, *SD* = 10) from theta estimates of IRT scores. Publishers of ECLS-K Math report the reliability of IRT-based scores as 0.91 in fall of kindergarten year and 0.93 in spring of kindergarten year (Tourangeau, Nord, Le, Sorongon, & Najarian, 2009).

In contrast to ECLS-K Math, Applied Problems was designed specifically to assess mathematics ability from ages 2–90 years (Woodcock et al., 2001). Items for young children include numeracy (“Show me two fingers”), counting (“How many cows are in this picture”), and addition/subtraction (“If you took away can one, how many would be left?”). Testing begins with item number one and progresses until the child responds incorrectly to six consecutive items. In the current sample, children answered on average 22 items at the preschool assessment and 31 at the kindergarten assessment. Scoring software was used to derive standardized W-scores based on IRT scoring. The W-score is based on an average score of 500, which is what a 10-year-old would be expected to score. Reported reliability is 0.94 for 4- to 5-year-olds (Woodcock et al., 2001).

2.3.4. Vocabulary—At the preschool assessment, data collectors administered the Peabody Picture Vocabulary Test—4th Edition (PPVT; Dunn & Dunn, 2007) as a measure of children's verbal intelligence. Children are presented colored drawings, four to a page, and asked to identify the picture that best represents the word spoken by the data collector. The measure consists of 228 items in 19 blocks and administration is discontinued after eight errors within a block. Raw scores are converted to standard scores with a mean of 100 and *SD* of 15. Developers of the measure have reported internal consistency coefficients across ages as 0.94 and the test-retest reliability as 0.93 (Dunn & Dunn, 2007).

2.3.5. Income-to-need ratio—Consistent with prior work (Hanson, McLanahan, & Thompson, 1995), income-to-need ratios were used as a measure of family income level. At 48 months, mothers reported income from all sources for each member of the household. An income-to-need ratio was calculated as total household income, divided by the federal poverty threshold for the particular year in which the data were collected, and adjusted for the number of household members. Income-to-need ratios were natural log transformed.

2.3.6. Covariates—Each of the prediction models included a number of child- and family-level covariates. Child ethnicity was coded as “1” for African American and “0” for not African American. Child sex was coded as “1” for male and “0” for female. Primary caregiver's level of education was coded as the number of years the primary caregiver had spent in school. The state in which the family resided was coded as “1” for North Carolina and “0” for Pennsylvania.

2.4. Data analysis

Because these analyses involved students nested within kindergarten classrooms, it was necessary to reduce potential bias in estimates due to non-independence of observations. As such we conducted multilevel model (MLM) analysis with a random intercept using the

TYPE = TWOLEVEL command in Mplus Version 7.0 (Muthén & Muthén, 2012). This analysis allows classroom means to vary around the grand mean and identifies the proportion of variance attributable to the classroom. All independent variables were added to the models at the individual level. All continuous variables were centered at the grand mean, providing an intercept that can be interpreted as an adjusted mean for each classroom (Raudenbush & Bryk, 2002).

Separate multilevel models were conducted for ECLS-K Math and Applied Problems. First, an unconditional means model estimated a grand mean for each kindergarten math score and the proportions of variance attributable to between-classroom and within-classroom levels. The equation for this model at the individual level is $Y_{ij} = \beta_{0j} + \varepsilon_{ij}$ where Y_{ij} is the kindergarten math score for child i in classroom j, β_{0j} is the adjusted intercept for classroom j, and ε_{ij} is the random error term that represents the residual (or unexplained) variation in the outcome and is assumed to have a normal distribution with a mean of 0 and variance of σ_{ε}^{2}. The equation for the unconditional means model at the classroom level is $\beta_{0j} = b_0 + \zeta_j$ where b_0 is the intercept and ζ_j is the error term that allows classroom means to vary around the intercept (grand mean) and is assumed to be independent from σ_{ε}^{2} and have a normal distribution with a mean of 0 and variance of σ_{ε}^{2}.

Second, we tested the main effects of our predictor variables by adding executive function EAP scores, teacher–child relationship ratings, and corresponding preschool math score variables to the models. The equations for this models at are:

$$\begin{aligned} \text{Level 1} \quad Y_{ij} &= \beta_{0j} + b_1 PreschoolMath_{ij} + b_2 ExecutiveFunction_{ij} \\ &\quad + b_3 TeacherChildRelationship_{ij} + b_6 Covariates_{ij} + \varepsilon_{ij} \\ \text{Level 2} \quad \beta_{0j} &= b_0 + \zeta_j \end{aligned}$$

where the covariates include family income-to-needs ratio, child's race and sex, primary caregiver's level of education, and state.

Third, we tested the moderating effect of executive function EAP scores and teacher–child relationships rating on the relation between preschool and kindergarten math scores by adding interaction terms between preschool math scores and teacher–child relationship ratings and between preschool math scores and executive function EAP scores. Variables were centered at the grand mean prior to creating interaction terms. The equations for this model are:

$$\begin{aligned} \text{Level 1} \quad Y_{ij} &= \beta_{0j} + b_1 PreschoolMath_{ij} + b_2 ExecutiveFunction_{ij} \\ &\quad + b_3 TeacherChildRelationship_{ij} \\ &\quad + b_4 (PreschoolMath * ExecutiveFunction)_{ij} \\ &\quad + b_5 (PreschoolMath * TeacherChildRelationship)_{ij} + b_6 Covariates_{ij} + \varepsilon_{ij} \\ \text{Level 2} \quad \beta_{0j} &= b_0 + \zeta_j \end{aligned}$$

Missing data—Total sample size recruited at study entry was 1292 with 1066 children seen at the 48-month home assessment, 991 children seen at the preschool assessment, and

1010 children seen at the kindergarten assessment. To assess possible differential attrition in the sample, we examined a number of variables for which we had complete information collected at child age of approximately 2 months, including state of residence, ethnicity, sex, child age at the 2-month follow up, income, total number of household members, number of children in the household, and primary caregiver age, education, marital status, and employment. Only child's ethnicity indicated differences such that families who were not included in our analytic sample were more likely to be African American.

Analyses included 1005 children with kindergarten math data. Among the included cases, 16% were missing preschool ECLS-K Math scores, 10% were missing preschool Applied Problems scores, 8% were missing the kindergarten teacher–child relationship ratings, 1% were missing executive function scores at 48-months, and less than 1% were missing one of the math assessments at kindergarten. To avoid bias in parameter estimates associated with missing data, we estimated our multilevel regression models using full information maximum likelihood (FIML) estimation with robust standard errors. FIML makes use of all the information present in the independent variables to estimate the covariance matrix and thus effectively allowed us to use the entire sample with data on the dependent variables (Enders & Bandalos, 2001).

3. Results

Descriptive statistics for demographic variables, predictor variables, and academic outcomes are shown in Table 1. As expected, children's math scores improved by more than a standard deviation from preschool to kindergarten on the ECLS-K Math, $M = 32.7$ ($SD = 6.56$) to 40.6 ($SD = 5.42$), and on Applied Problems, $M = 407.5$ ($SD = 21.73$) to 431.1 ($SD = 19.29$). Correlations among predictor variables and math measures are displayed in Table 2. ECLS-K Math and Applied Problems scores were highly correlated at preschool, $r = 0.70$ and at kindergarten, $r = 0.67$. Preschool to kindergarten assessments of the same measures were also highly correlated, although more so for Applied Problems, $r = 0.71$, than for ECLS-K Math, $r = 0.57$. The executive function EAP score was highly correlated with math scores in preschool and kindergarten, rs = 0.44 to 0.52. Teacher–Child relationship ratings were modestly correlated with math scores in preschool and kindergarten, rs = 0.17 to 0.23.

3.1. Multilevel regression results

Table 3 presents the unconditional means models predicting mathematics ability in kindergarten for the ECLS-K Math and Applied Problems measures in separate models. Intraclass correlation coefficients (ICC) indicated that with no predictors in the model, 16% of the variance in kindergarten ECLS-K Math scores and 32% of the variance in kindergarten Applied Problems scores were attributable to the classroom level.

Table 4 presents the results for the multilevel regression models predicting both of the kindergarten math assessments. Model 1 includes covariates, ratings of teacher–child relationship quality, the composite measure of executive function, and the respective preschool math score for each of the kindergarten math outcomes. The addition of the covariates and predictors reduced residual variances from 24.69 in the unconditional means model to 16.24 for ECLS-K Math and from 259.90 to 141.60 for Applied Problems, a

difference of 34% and 46%, respectively. The corresponding reduction in the ICC from the unconditional means models was from 0.16 to 0.09 for ECLS-K Math and from 0.32 to 0.13 for Applied Problems, a difference of 43% and 49%, respectively.

As expected, in separate models, math scores in preschool significantly predicted math scores in kindergarten for both ECLS-K Math and Applied Problems, $b = 0.29$, $SE = 0.03$, $p < .001$ and $b = 0.44$, $SE = 0.04$, $p < .001$, respectively, with effect sizes of $\beta = 0.37$ and $\beta = 0.52$ (Table 4). Boys scored higher than did girls on both measures, ECLS-K Math, $\beta = 0.07$, $b = 0.70$, $SE = 0.27$, $p = .008$, and Applied Problems, $\beta = 0.05$, $b = 1.87$, $SE = 0.86$, p = .029. Child age was positively related to ECLS-K Math scores at a trend level, $\beta = 0.05$, $b = 0.93$, $SE = 0.49$, p = .057, and significantly predicted Applied Problems scores, $\beta = 0.06$, $b = 4.12$, $SE = 1.58$, p = .009. Vocabulary measured in preschool was positively related to ECLS-K Math scores, $\beta = 0.18$, $b = 0.06$, $SE = 0.01$, $p < .001$, and Applied Problems scores, $\beta = 0.19$, $b = 0.23$, $SE = 0.05$, $p < .001$.

Also as reported in Table 4, the composite measure of executive function in preschool was positively related to both measures of math, ECLS-K Math, $b = 1.46$, $SE = 0.35$, $p < .001$, and Applied Problems, $b = 5.56$, $SE = 1.30$, $p < .001$, with similar effect size, $\beta = 0.14$ and $\beta = 0.15$, respectively. In contrast to executive function, the main effect of the quality of the teacher–child relationship in kindergarten was not consistent across the two measures of math ability in kindergarten. Children reported as having a higher quality relationship with the kindergarten teacher had higher ECLS-K Math scores in kindergarten, $b = 0.43$, $SE = 0.25$, $p = .084$, at a trend-level of statistical significance with a small effect size, $\beta = 0.05$, whereas the quality of the teacher–child relationship was unrelated to the Applied Problems subtest.

3.1.1. Moderating effects of teacher–child relationships and executive function

—Model 2 in Table 4 presents the test of our key hypothesis that executive function abilities and the quality of the relationship with the kindergarten teacher will each moderate the effect of math ability in preschool on math ability in kindergarten. Executive function scores at 48 months significantly moderated the association between preschool math ability and kindergarten math ability as assessed by the ECLS-K Math assessment, $\beta = -0.14$, $b = -0.11$, $SE = 0.05$, $p = .019$, but not the Applied Problems test. This interaction is shown in Fig. 1. Follow-up tests of the simple slopes indicated that the association between preschool and kindergarten ECLS-K Math scores was stronger among children with lower levels of executive function, $\beta = 0.37$, $p < .001$, than among children with higher levels of executive function, $\beta = 0.24$, $p < .001$.

The interaction of teacher–child relationship quality with mathematics ability in preschool also significantly predicted mathematics in kindergarten on the ECLS-K Math measure, $\beta = -0.08$, $b = -0.23$, $SE = 0.05$, $p < .001$, but not the Applied Problems subtest. Fig. 2 illustrates the interaction. Again, the association between preschool and kindergarten ECLS-K Math Scores was stronger among children with a less positive relationship with the kindergarten teacher, $\beta = 0.47$, $p < .001$, compared to children with a more positive relationship with the kindergarten teacher, $\beta = 0.30$, $p < .001$.

4. Discussion

The primary aim of this study was to examine the extent to which executive function abilities and the quality of relationships that children form with kindergarten teachers might moderate the association between math ability in preschool and math ability in kindergarten. Specifically, we were interested in whether these aspects of children's readiness for school might compensate for or buffer poor academic preparedness. We found that children's executive function abilities at age 48 months and higher quality relationships with the kindergarten teachers each uniquely moderated the development of math ability from preschool to kindergarten. This effect was seen for math ability as measured by the ECLS-K math assessment but not the Applied Problems subtest. For children with lower math ability in preschool as assessed by the ECLS-K Math battery, higher executive function abilities and a more positive relationship with the kindergarten teacher were each associated with a higher than expected levels of math ability in kindergarten.

4.1. Moderators of preschool and kindergarten math ability

It is well known that measures of academic ability are moderately to highly stable in early childhood (La Paro & Pianta, 2000) and that the best predictor of later ability is early ability (Duncan et al., 2007). In the study of early academic ability, however, a growing literature demonstrates that measures of executive function in young children account for meaningful variation in academic outcomes, particularly mathematics, even when controlling for prior academic ability and measures of general intelligence and vocabulary (Blair & Razza, 2007; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; McClelland et al., 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010). As well, a growing body of research on the teacher–child relationship has shown that positive relationships with teachers and the absence of conflict with teachers are uniquely related to later academic ability, even when controlling for measures of earlier ability and classroom quality (Hamre & Pianta, 2001; Howes et al., 2008).

Although the prior literature is clear about the presence of multiple influences on academic ability in early childhood, few studies have examined relations among these predictors. This is particularly the case for samples of children at risk for early school difficulty due to socioeconomic status. From a theoretical standpoint, it is logical that executive function abilities and the quality of relationships with teachers would matter most for children with a lower level of prior ability. Notably, such a hypothesis of moderation is consistent with somewhat dated but nonetheless intriguing evidence from a nationally representative survey of kindergarten teachers indicating that teachers perceive self-regulation skills and abilities to be more important for school readiness than early academic skills (Heaviside & Farris, 1993). Executive function skills provide the platform for acquiring and making sense of increasingly complex information and for reflecting on that information and generating conceptual structures through which it is organized. As such, executive functions are one important component of self-regulated learning and the metacognitive abilities that are important contributors to academic learning (Perry & Winne, 2013).

To date, there has been limited research on influences on metacognitive development in young children (Bryce & Whitebread, 2012). Our results suggest the potential value of a

focus on self-regulation, including executive function as well as social competence as indicated by the child's relationship with the teacher, in research on metacognitive development and self-regulated learning in children. Although the relation of executive functioning to processes of learning is relatively clear, a similar case can be made for the teacher–child relationship. Teachers provide more explanation and scaffolding for children with whom they report a close relationship (Allington, 1984; Nomi, 2009). As well, kinder-gartners with close relationships to teachers demonstrate greater self-direction and enjoyment in school activities, and are better able to manage frustration (Birch & Ladd, 1997; Pianta et al., 1995).

Notably, the observed moderation of early academic ability by the measure of EF and the teacher–child relationship was seen over and above an effect for child receptive vocabulary. Receptive vocabulary is frequently considered to be a marker of general ability and is moderately correlated with executive function abilities and teacher–child relationships in these and other data (e.g., Blair & Razza, 2007; Bull et al., 2011; Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Justice, Cottone, Mashburn, & Rimm-Kaufman, 2008). That interactions of executive function ability and teacher–child relationships with early ability explain unique variation in kindergarten math ability over-and-above receptive vocabulary adds strength to our findings.

4.2. Measuring mathematics ability

Further, as noted in the introduction, we focus specifically on early mathematics learning for methodological and conceptual reasons. Based on the foregoing, however, we expect that our findings may generalize to other aspects of early learning in school, particularly those aspects that are associated with reasoning and abstraction, such as reading comprehension and science learning. Executive function abilities and the teacher–child relationship are positively related to reading, language, and general classroom engagement in preschool and kindergarten (Birch & Ladd, 1997; Burchinal et al., 2002; Fuhs & Day, 2011; Harrison, Clarke, & Ungerer, 2007; Jones, Bub, & Raver, 2013). A key point for this analysis, however, concerns that fact that evidence for the moderation of early mathematics ability by executive functions and the quality of the teacher–child relationship was seen only for one of the measures of mathematics ability. Children with lower level of mathematics ability in preschool as assessed by the ECLS-K Math battery but not the Applied Problems subtest made greater improvements in math performance in kindergarten when characterized by higher levels of executive functions or more positive relationships with kindergarten teachers.

This discrepancy is of interest in that both measures are highly reliable and valid. The ECLS-K Math battery, however, was designed specifically for use in early childhood while the Applied Problems subtest was designed for use across the lifespan. As such, the ECLS-K Math battery is more sensitive to variation in ability among young children. Unlike the Applied Problems subtest, on the ECLS-K Math battery children are routed to distinct ability levels. Children also complete a greater number of items across a wider range of domains of mathematics. Consequently, despite similar internal consistency reliability and criterion related validity, the stability of the Applied Problems subtest, $r = 0.71$, in this

sample was considerably higher than that for the ECLS-K Math battery, $r = 0.57$. The smaller amount of variance in the kindergarten assessment of the ECLS-K Math battery accounted for by the preschool assessment allows for the detection of relatively small effects such as those associated with the interaction terms. Both measures are excellent measures of the construct and are highly correlated at each time point. Our findings, however, indicate that studies that rely exclusively on the Applied Problems subtest, a widely used measure of mathematics ability in children, are likely to miss small but meaningful influences on math achievement.

4.3. Limitations and future directions

Although the strengths of the present study include a prospective, longitudinal design with extensive assessment of executive functions and mathematics ability, findings should be interpreted with certain limitations in mind. First, although the design is longitudinal, and as such inference is relatively strong, associations between variables are correlational and cannot be interpreted as causal. A further potential limitation of the research concerns the absence of information on classroom climate or instructional practices. Both are important influences on child academic achievement. A prior analysis with the NICHD SECCYD data set found that the effect of teacher–child relationship quality on growth in math achievement between third and fifth grade was observed only in classrooms in which instructional quality was high as indicated by inferential instructional techniques (Crosnoe et al., 2010). Given this prior finding, it is conceivable that with information on instructional quality we might have detected even larger interactions of executive functions and teacher–child relationship quality with preschool mathematics knowledge in classrooms in which instructional quality was high. Indeed, it is possible that our detection of interaction effects would have also extended to the Applied Problems subtest, the measure of mathematics ability included in the SECCYD.

A third limitation concerns the suitability of the measures of mathematics ability as measures of academic learning. Our hypotheses are concerned with the premise that executive functions and the relationship with the teacher are important for the process of learning. The standardized measures that are our outcome variables, however, are measures of acquired ability. Presumably, these measures are valid indicators of the learning process. Research examining associations of executive function and related constructs to processes of learning, ideally in experimental evaluations of activities designed to foster self-regulated learning (e.g., Fuchs et al., 2003), can address this important point.

A fourth limitation concerns the possibility that the findings may be somewhat specific to the predominantly low-income populations to which this sample would be expected to generalize. Children in poverty are less likely than their more advantaged peers to experience early rearing environments that provide learning opportunities in math and reading and the rich and varied exposure to language that are known to be important for early academic success (Bradley, Corwyn, McAdoo, & García Coll, 2001; Evans, 2004). For children with limited opportunity for learning prior to kindergarten, executive function abilities and the experience of a positive relationship with the teacher would be expected to offset early disadvantage. It remains to be seen, however, whether the moderating effects

observed in this predominantly low-income sample would extend across the range of SES. Interactions of executive functions and teacher–child relationship quality with mathematics ability in preschool were seen at the lower end of the distribution of preschool math ability but not the high end. As such it may be that the potential to detect moderating effects of the teacher–child relationship and executive function skills on mathematics in kindergarten was maximized and estimates of effects may be large relative to those expected in the general population.

5. Conclusions

Our findings highlight the interrelatedness of influences on school readiness, particularly for children with low levels of academic preparedness for school. While early math ability, executive function, and a higher quality teacher–child relationship have all been shown to be important for school readiness, it is encouraging that strength in a particular area can help to compensate for weaknesses in another. This point appears to be particularly applicable to children with poor academic preparedness associated with poverty. If executive function skills or positive relationships with teachers are associated with greater than expected progress in mathematics learning, this would suggest the efficacy of innovative approaches to promoting early school progress that focus on self-regulation and social competence. To this end, our results are consistent with findings from experimental evaluations of programs to promote school readiness for children in poverty, such as the Chicago School Readiness Project (Raver et al., 2011) in which an intervention focused on child behavior problems led to improvements in child executive functions, classroom climate, and academic ability in reading and math at the end of preschool year. Similar findings were also obtained in an experimental evaluation of the Tools of the Mind program (Blair & Raver, 2014). Children in kindergarten classrooms randomly assigned to implement Tools of the Mind had higher levels of executive function ability and academic achievement relative to children in classrooms randomly assigned to the control group. These effects were particularly large, as much as a half of a standard deviation, for children in classrooms in high poverty schools.

In addition, our findings provide support for kindergarten teachers' perceptions of school readiness. As reported in a nationally representative survey (Heaviside & Farris, 1993), teachers endorsed a conception of readiness characterized by self-regulation as opposed to acquired academic skills and abilities. This conception of school readiness is one in which children arrive at school with the self-regulation skills that support engagement in the classroom and that allow for effective teaching and learning. Our findings are consistent with this view and help to make clear that while academic preparation prior to school entry is certainly important, when children enter school with the self-regulation characteristics that teachers indicate as essential to readiness, they are increasingly likely to make academic progress regardless of prior indicators of ability.

Acknowledgments

We would like to thank the many families and research assistants that made this study possible. Support for this research was provided by the National Institute of Child Health and Human Development grants R01 HD51502 and P01 HD39667 with co-funding from the National Institute on Drug Abuse. The Family Life Project Key Investigators include Lynne Vernon-Feagans, The University of North Carolina, Mark Greenberg, The Pennsylvania State University, Martha Cox, The University of North Carolina, Clancy Blair, New York University, Peg Burchinal,

The University of North Carolina, Michael Willoughby, The University of North Carolina, Patricia Garrett-Peters, The University of North Carolina, Roger Mills-Koonce, The University of North Carolina, Maureen Ittig, The Pennsylvania State University.

References

Allington RL. Content coverage and contextual reading in reading groups. Journal of Literacy Research. 1984; 16(2):85–96.

Baker D, Knipe H, Cummings E, Collins J, Gamson D, Blair C, et al. The fall and rise of American primary school mathematics: a content analysis and cognitive assessment of textbooks from 1900 to 2000. Journal of Research in Mathematics Education. 2010; 41:383–423.

Birch SH, Ladd GW. The teacher–child relationship and children's early school adjustment. Journal of School Psychology. 1997; 35(1):61–79.

Blair C, Knipe K. Is there a role for executive functions in the development of mathematics ability? Mind, Brain and Education. 2008; 2:80–89.

Blair C, Raver CC. Closing the achievement gap through modification of neurocognitive and neuroendocrine function: results from a cluster randomized controlled trial of an innovative approach to the education of children in kindergarten. PLoS ONE. 2014; 9(11):e112393. http://dx.doi.org/10.1371/journal.pone.0112393. [PubMed: 25389751]

Blair C, Raver CC. School readiness and self-regulation: a developmental psychobiological approach. Annual Review of Psychology. 2015; 66:711–731.

Blair C, Razza RP. Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development. 2007; 78(2):647–663. [PubMed: 17381795]

Bradley RH, Corwyn RF, McAdoo HP, García Coll C. The home environments of children in the united states part I: variations by age, ethnicity, and poverty status. Child Development. 2001; 72(6): 1844–1867. [PubMed: 11768149]

Brooks-Gunn J, Duncan GJ. The effects of poverty on children. The Future of Children. 1997; 7(2): 55–71. [PubMed: 9299837]

Bryce D, Whitebread D. The development of metacognitive skills: evidence from observational analysis of young children's behavior during problem-solving. Metacognition and Learning. 2012; 7:197–217.

Bull R, Espy KA, Wiebe SA. Short-term memory, working memory, and executive functioning in preschoolers: longitudinal predictors of mathematical achievement at age 7 years. Developmental Neuropsychology. 2008; 33(3):205–228. [PubMed: 18473197]

Bull R, Espy KA, Wiebe SA, Sheffield TD, Nelson JM. Using confirmatory factor analysis to understand executive control in preschool children: sources of variation in emergent mathematic achievement. Developmental science. 2011; 14(4):679–692. [PubMed: 21676089]

Burchinal M, Howes C, Pianta R, Bryant D, Early D, Clifford R, et al. Predicting child outcomes at the end of kindergarten from the quality of prekindergarten teacher–child interactions and instruction. Applied Development Science. 2008; 12:140–153. http://dx.doi.org/10.1080/10888690802199418.

Burchinal MR, Peisner-Feinberg E, Pianta R, Howes C. Development of academic skills from preschool through second grade: family and classroom predictors of developmental trajectories. Journal of School Psychology. 2002; 40:415–436.

Crosnoe R, Morrison F, Burchinal M, Pianta R, Keating D, Friedman SL, et al. Instruction, teacherestudent relations, and math achievement trajectories in elementary school. Journal of Educational Psychology. 2010; 102(2):407–417. http://dx.doi.org/10.1037/a0017762. [PubMed: 20657743]

Dill, BT. Rediscovering rural America. In: Blau, JR., editor. The blackwell companion to sociology. Blackwell; Oxford: 2001. p. 196-210.

Duncan, GJ., Brooks-Gunn, J. Consequences of growing up poor. Russell Sage Foundation Press; New York: 1997.

Duncan GJ, Dowsett CJ, Claessens A, Magnuson K, Huston AC, Klebanov P, et al. School readiness and later achievement. Developmental Psychology. 2007; 43(6):1428–1446. [PubMed: 18020822]

Dunn, DM., Dunn, LM. Peabody picture vocabulary test. 4th. Pearson; Minneapolis, MN: 2007.

Enders CK, Bandalos DL. The relative performance of full information maximum likelihood estimation for missing data in structural equation models. Structural Equation Modeling. 2001; 8:430–457.

Evans GW. The environment of childhood poverty. American Psychologist. 2004; 59(2):77–92. [PubMed: 14992634]

Fitzpatrick C, McKinnon RD, Blair C, Willoughby MT. Do preschool executive function skills explain the school readiness gap between advantaged and disadvantaged children? Learning and Instruction. 2014; 30:25–31.

Fuchs LS, Fuchs D, Prentice K, Burch M, Hamlett CL, Owen R, et al. Enhancing third-grade student's mathematical problem solving with self-regulated learning strategies. Journal of Educational Psychology. 2003; 95:306–315.

Fuhs MW, Day JD. Verbal ability and executive functioning development in preschoolers at head start. Developmental Psychology. 2011; 47:404–416. [PubMed: 21142363]

Hamre B, Hatfield B, Pianta R, Jamil F. Evidence for general and domain-specific elements of teacher–child interactions: associations with preschool children's development. Child Development. 2014; 85:1257–1274. [PubMed: 24255933]

Hamre BK, Pianta RC. Early teacher–child relationships and the trajectory of children's school outcomes through eighth grade. Child Development. 2001; 72(2):625–638. http://dx.doi.org/10.1111/1467-8624.00301. [PubMed: 11333089]

Hanson, TL., McLanahan, SS., Thomson, E. Economic resources, parental practices, and children's well-being. In: Duncan, G., Brooks-Gunn, J., editors. Consequences of growing up poor. Russell Sage Foundation; New York: 1995. p. 190-221.

Harrison LJ, Clarke L, Ungerer JA. Children's drawings provide a new perspective on teacher–child relationship quality and school adjustment. Early Childhood Research Quarterly. 2007; 22:55–71.

Heaviside, S., Farris, E. Fast Response Survey System. US Government Printing Office, Superintendent of Documents, Mail Stop: SSOP; Washington, DC 20402-9328: 1993. Public School Kindergarten Teachers' Views on Children's Readiness for School. Contractor Report. Statistical Analysis Report.

Howes C, Burchinal M, Pianta R, Bryant D, Early D, Clifford R, et al. Ready to learn? Children's pre-academic achievement in pre-kindergarten programs. Early Childhood Research Quarterly. 2008; 23:27–50.

Jacques S, Zelazo PD. The flexible item selection task (FIST): a measure of executive function in preschoolers. Developmental Neuropsychology. 2001; 20(3):573–591. [PubMed: 12002094]

Jones SM, Bub KL, Raver CC. Unpacking the black box of the Chicago school readiness project intervention: the mediating roles of teacher–child relationship quality and self-regulation. Early Education & Development. 2013; 24:1043–1064. [PubMed: 24729666]

Justice LM, Cottone EA, Mashburn A, Rimm-Kaufman SE. Relationships between teachers and preschoolers who are at risk: contribution of children's language skills, temperamentally based attributes, and gender. Early Education and Development. 2008; 19:600–621.

La Paro KM, Pianta RC. Predicting children's competence in the early school years: A meta-analytic review. Review of educational research. 2000; 70(4):443–484.

Liew J, Chen Q, Hughes JN. Child effortful control, teacherestudent relationships, and achievement in academically at-risk children: additive and interactive effects. Early Childhood Research Quarterly. 2010; 25:51–64. [PubMed: 20161421]

McClelland MM, Cameron CE, Connor CMD, Farris CL, Jewkes AM, Morrison FJ. Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. Developmental Psychology. 2007; 43(4):947–959. http://dx.doi.org/10.1037/0012-1649.43.4.947. [PubMed: 17605527]

Muthén, LK., Muthén, BO. Mplus users guide. 6th. Muthén & Muthén; Los Angeles, CA: 2012.

Noble KG, McCandliss BD, Farah MJ. Socioeconomic gradients predict individual differences in neurocognitive abilities. Developmental Science. 2007; 10(4):464–480. [PubMed: 17552936]

Nomi T. The effects of within-class ability grouping on academic achievement in early elementary years. Journal of Research on Educational Effectiveness. 2009; 3(1):56–92.

Perry, NE., Winne, PH. Tracing students' regulation of learning in complex collaborative tasks. In: Volet, S., Vauras, M., editors. Interpersonal regulation of learning and motivation: Methodological advances. Routledge; New York NY: 2013. p. 45-66.

Pianta RC, La Paro KM, Payne C, Cox MJ, Bradley R. The relation of kindergarten classroom environment to teacher, family, and school characteristics and child outcomes. The Elementary School Journal. 2002; 102:225–238. doi http://www.jstor.org/stable/1002217.

Pianta RC, Steinberg MS, Rollins KB. The first two years of school: teacher–child relationships and deflections in children's classroom adjustment. Development and Psychopathology. 1995; 7(2): 295–312. http://dx.doi.org/10.1017/S0954579400006519.

Raudenbush, SW., Bryk, AS. Hierarchical linear models: Applications and data analysis methods. Vol. 2. Sage; Thousand Oaks, CA: 2002.

Raver CC, Jones SM, Li-Grining C, Zhai F, Bub K, Pressler E. CSRP's impact on low-income preschoolers' preacademic skills: self-regulation as a mediating mechanism. Child Development. 2011; 82(1):362–378. [PubMed: 21291447]

Reardon, SF. The widening socioeconomic status achievement gap: New evidence and possible explanations. In: Murnane, RJ., Duncan, GJ., editors. Whither Opportunity? Rising Inequality and the Uncertain Life Chances of Low-Income Children. Russell Sage Foundation; New York: 2011. p. 91-116.

Rock, DA., Pollack, JM. Working paper series. ED Pubs; Jessup, MD: 2002. Early childhood longitudinal study-kindergarten class of 1998–99 (ECLS-K): Psychometric report for kindergarten through first grade.

Schmitt MB, Pentimonti JM, Justice LM. Teacher–Child relationships, behavior regulation, and language gain among at-risk preschoolers. Journal of School Psychology. 2012; 50:681–699. [PubMed: 23040762]

Tourangeau, K., Nord, C., Le, T., Sorongon, AG., Najarian, M. Early childhood longitudinal study, kindergarten class of 1998-99 (ECLS-K): Combined user's manual for the ECLS-K eighth-grade and K-8 full sample data files and electronic codebooks. National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education; Washington, DC.: 2009. No. NCES 2009–004

Vernon-Feagans L, Cox M, Key Investigators, F. L. P. The family life project: an epidemiological and developmental study of young children living in poor rural communities. Monographs of the Society for Research in Child Development. 2013; 78(5)

Welsh JA, Nix RL, Blair C, Bierman KL, Nelson KE. The development of cognitive skills and gains in academic school readiness for children from low-income families. Journal of Educational Psychology. 2010; 102:43–53. http://dx.doi.org/10.1037/a0016738. [PubMed: 20411025]

Willoughby MT, Blair C. Test-retest reliability of a new executive function battery for use in early childhood. Child Neuropsychology. 2011; 17(6):564–579. [PubMed: 21714751]

Willoughby MT, Wirth R, Blair CB. Contributions of modern measurement theory to measuring executive function in early childhood: an empirical demonstration. Journal of Experimental Child Psychology. 2011; 108(3):414–435. [PubMed: 20553690]

Willoughby MW, Wirth RJ, Blair C, the FLP Investigators. Executive function in early childhood: Longitudinal measurement invariance and developmental change. Psychological Assessment. 2012; 24:418–431. [PubMed: 22023561]

Woodcock, RW., McGrew, KL., Mather, N. Woodcock-Johnson-III tests of achievement and cognitive abilities. Riverside; Itasca, IL: 2001.

Zimmerman BJ. Investigating self-regulation and motivation: historical background, methodological developments, and future prospects. American Educational Research Journal. 2008; 45:166–183.

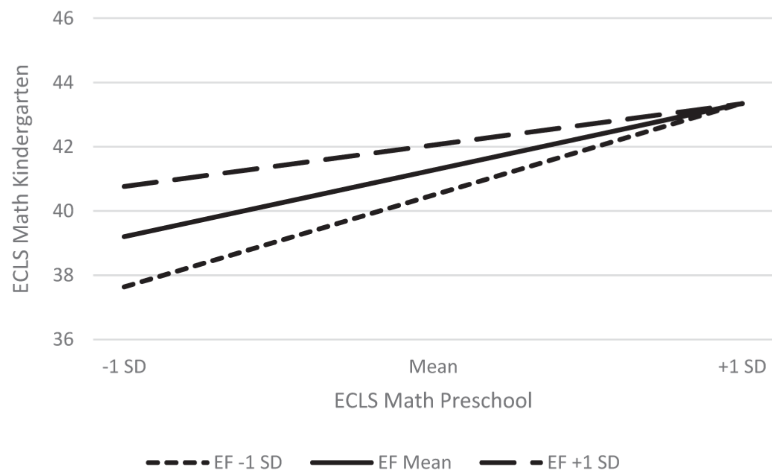

Fig. 1.
Executive function moderates the relation between preschool and kindergarten ECLS-K Math, holding all other covariates constant at mean levels.

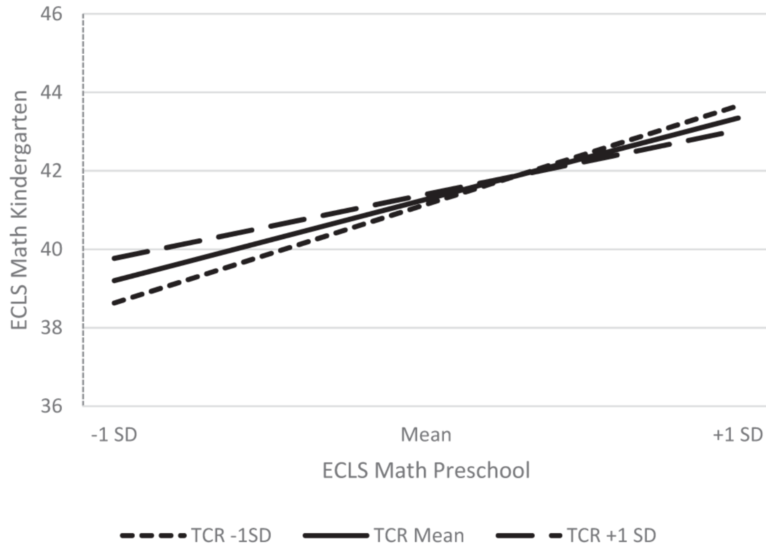

Fig. 2.

Teacher–Child relationship moderates the relation between preschool and kindergarten ECLS-K Math, holding all other covariates constant at mean levels.

Table 1

Demographic information and descriptive statistics for predictor variables and academic outcomes.

Variable	Mean/%	SD	Minimum	Maximum	N
Age at K	5.95	0.28	5.40	6.69	1005
Ethnicity					
Caucasian	54%				543
African American	45%				456
Native American	0.3%				3
Asian	0.2%				2
Pacific Islander	0.1%				1
Male	49%				1005
Income-to-Need Ratio	1.63	1.33	0.00	15.80	914
Vocabulary	94.02	15.52	46.00	135.00	907
EF	−0.13	0.51	−2.14	1.23	920
Teacher–Child Relationship	4.34	0.62	2.13	5.00	928
Early Math Outcomes					
ECLS-K Math P	32.64	6.56	16.44	51.36	839
ECLS-K Math K	40.58	5.42	18.13	55.67	1003
AP Math P	407.52	21.73	318.00	458.00	907
AP Math K	431.10	19.29	318.00	481.00	1003

Note. K = Kindergarten; EF = Executive Function; TCR = Teacher Child Relationship; P = Preschool; AP = Applied Problems.

Table 2

Correlations among predictor and academic outcome variables.

		1	2	3	4	5	6	7
1	TCR	–						
2	EF	0.20**	–					
3	Vocabulary	0.25**	0.57**	–				
4	ECLS-K Math P	0.22**	0.50**	0.61**	–			
5	ECLS-K Math K	0.20**	0.46**	0.51**	0.57**	–		
6	Applied Problems P	0.23**	0.52**	0.65**	0.70**	0.61**		
7	Applied Problems K	0.17**	0.53**	0.60**	0.62**	0.67**	0.71**	–

Note.

TCR = Teacher Child Relationship; EF = Executive Function; P = Preschool; K = Kindergarten.

* $p < .05$;

** $p < .01$;

*** $p < .001$;

Author Manuscript

Author Manuscript

Author Manuscript

Table 3

Unconditional means models for both kindergarten math measures.

	ECLS-K Math		AP math	
	b	***SE***	***b***	***SE***
Intercept	40.73***	0.19	431.66***	0.74
Classroom variance	4.66	1.40	121.89	39.69
Residual variance	24.69	1.57	259.90	17.64
ICC	0.16		0.32	

Note.

AP = Applied Problems.

* $p < .05$;

** $p < .01$;

*** $p < .001$;

Table 4

Regression coefficients predicting kindergarten mathematics ability from executive function and teacherechild relationships.

	ECLS-K Math				Applied problems			
	Model 1		Model 2		Model 1		Model 2	
	β	*b (SE)*	β	*b (SE)*	β	*b (SE)*	β	*b (SE)*
Intercept	31.75	40.46 (0.28) ***	34.04	41.03 (0.29) ***	94.39	430.61 (0.90) ***	98.13	431.15 (0.95) ***
Age at K	0.05	0.93 (0.49) †	0.05	0.95 (0.49) †	0.06	4.12 (1.58) **	0.07	4.40 (1.61) **
Ethnicity	−0.05	−0.54 (0.40)	−0.06	−0.60 (0.39)	0.00	−0.01 (1.35)	0.00	0.01 (1.36)
Sex (Male = 1)	0.07	0.70 (0.27) **	0.06	0.58 (0.26) *	0.05	1.87 (0.86) *	0.05	1.82 (0.85) *
Caregiver Education	0.05	0.09 (0.07)	0.06	0.12 (0.07) †	0.01	0.07 (0.21)	0.01	0.08 (0.21)
State (NC = 1, PA = 0)	0.04	0.39 (0.39)	0.03	0.35 (0.38)	0.00	−0.14 (1.16)	−0.01	−0.31 (1.17)
Income-to-Need (nLog)	−0.01	−0.04 (0.15)	−0.02	−0.06 (0.15)	−0.02	−0.23 (0.54)	−0.01	−0.21 (0.54)
Vocabulary	0.18	0.06 (0.01) ***	0.17	0.06 (0.02) ***	0.19	0.23 (0.05) ***	0.19	0.23 (0.05) ***
Math Preschool	0.37	0.29 (0.03) ***	0.39	0.31 (0.03) ***	0.52	0.44 (0.04) ***	0.51	0.43 (0.04) ***
TCR	0.05	0.43 (0.25) †	0.03	0.21 (0.24)	−0.01	−0.22 (0.82)	−0.01	−0.24 (0.77)
EF	0.14	1.46 (0.35) ***	0.15	1.52 (0.36) ***	0.15	5.56 (1.30) ***	0.16	5.75 (1.31) ***
Interactions								
TCR*Preschool Math			−0.14	−0.23 (0.05) ***			−0.05	−0.08 (0.05)
EF*Preschool Math			−0.08	−0.11 (0.05) *			0.00	0.00 (0.06)
Classroom Variance		1.62 (0.68) *		1.45 (0.65) *		20.81 (10.75) †		19.30 (10.71) †
Residual Variance		16.24 (0.94) ***		15.62 (0.95) ***		141.60 (12.43) ***		142.06 (12.46) ***
Model R^2		0.41		0.44		0.59		0.59
ICC		0.09		0.09		0.13		0.12

Note.

AP = Applied Problems; K = Kindergarten; TCR = Teacher Child Relationship; EF = Executive Function.

† $p < .10$;

* $p < .05$;

** $p < .01$;

*** $p < .001$;